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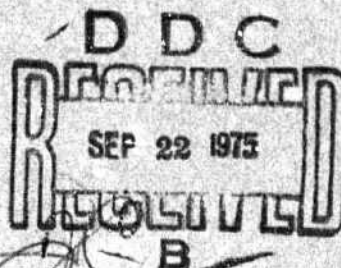
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75-108-AMEL

**ACQUISITION OF DROP HEIGHT DATA  
DURING PACKAGE HANDLING OPERATIONS**

by

Franklin D. Barca



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June 1975

UNITED STATES ARMY  
NATICK DEVELOPMENT CENTER  
NATICK, MASSACHUSETTS 01760



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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 75-108-AMEL	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ACQUISITION OF DROP HEIGHT DATA DURING PACKAGE HANDLING OPERATIONS		5. TYPE OF REPORT & PERIOD COVERED Final rept. April 1971 - December 1974.
7. AUTHOR(s) Franklin D. Barca		6. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Aero-Mechanical Engineering Laboratory U.S. Army Natick Development Center Natick, Massachusetts 01760		10. PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS 1T762713D522 05/012
11. CONTROLLING OFFICE NAME AND ADDRESS Aero-Mechanical Engineering Laboratory U.S. Army Natick Development Center Natick, Massachusetts 01760		12. REPORT DATE June 1975
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) N - 75-108-AMEL		13. NUMBER OF PAGES 19
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) DA-2-T-762713-D-503 1-T-762713-D-503		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) <div style="display: flex; justify-content: space-between;"> <div>           DROP HEIGHT IMPACT RECORDERS TRANSPORTATION MATERIALS HANDLING SHOCK         </div> <div>           CONTAINERS LOADS STORAGE PACKAGING         </div> <div>           DATA ENVIRONMENT HANDLING SHIPPING         </div> </div>		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report summarizes the results of various package handling studies conducted with 41cm x 31cm x 24cm, 11.3 kg containers which were instrumented with small battery operated drop height recorders and routed thru various transportation systems.		

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## **PREFACE**

This work was accomplished under the US Army Natick Development Center Project entitled "Packaging Technology — Establishment of Design Criteria for Containers — Acquisition of Shock, Load and Climatic Data During Transportation and Storage of Containers". This is Project Number 1T762713D552, Task Number 05, Work Unit Number 012.

## TABLE OF CONTENTS

	Page
List of Figures	3
I. Introduction	4
II. Measuring and Recording Systems	4
III. System Preparation	8
IV. Shipment	11
V. Results	12
A. Operational Problems	12
B. System Accuracy	13
C. Recorded Data	14
VI. Concluding Remarks	17
VII. Future Effort	18
References	19



## LIST OF FIGURES

	Page
Figure 1. Drop Height Recorder, Top View	6
Figure 2. Drop Height Recorder, Bottom View	6
Figure 3. Protective Cover	7
Figure 4. Drop Height Sensor	7
Figure 5. Preparation of Instrumented Container for Shipment	9
Figure 6. Representative Calibration Series, Oscilloscope Trace	10
Figure 7. Representative Shipment Series, Oscilloscope Trace	10
Figure 8. Frequency Histogram of Recorded Drops	15
Figure 9. Relative Frequency of Recorded Drops	16
Figure 10. Drop Height Probability Distribution	16

## I. INTRODUCTION

The U.S. Army Natick Development Center is engaged in a continuing investigation directed toward obtaining quantitative data on the actual container transportation environment to be used as a factual basis for scientific container design and laboratory transportation environment simulation tests.

This report is a summary of those experimental studies which were conducted in the area of acquisition of drop height data during package handling operations. It presents the results of field studies conducted, during the time period of April 1971 to December 1974, to obtain reliable data on the drop heights experienced by packages in shipment. The data were collected with drop height recorders placed inside the packages and are presented to provide a record of the instrumentation use as well as to indicate the type of information which can be collected utilizing the drop height recording system. Some of the studies were made during the period of testing and improving the instrumentation.

## II. MEASURING AND RECORDING SYSTEMS

The U.S. Army Natick Development Center has developed through in-house and contractual efforts three environmental recording systems for instrumenting shipping containers. Each system consists basically of a small lightweight, four-channel, battery operated tape recorder and the appropriate environmental sensors. The units are placed in containers which are incorporated into regular shipments and which monitor conditions for a maximum period of six months. Upon completion of the shipment the magnetic tape is removed from the unit, and the recorded data is retrieved by processing the tape thru a precision tape deck and suitable display device or retrieval system as detailed in reference (1). A brief description of each system follows.

The acceleration recording system, described in reference (2), records the number of impacts, the impact magnitude, and the approximate impact time for the three principal axes of a container. It is impact actuated and has a range of five to one thousand g's. One unit has been prototyped.

The temperature/humidity recording system, described in reference (3), records the temperature and relative humidity inside of a package at one hour increments over the ranges of  $-40^{\circ}\text{C}$  to  $65^{\circ}\text{C}$  and 10% RH to 95% RH. A capability for the hourly recording of other data such as the static compressive load on the package also exists. Twelve systems have been manufactured and are being used in continuing studies to develop data on the temperature and humidity conditions for various routes and modes of transportation and under many storage conditions. Reference (4) details the results of actual field studies conducted with these systems from April 1971 to July 1973.

The drop height recording system described in reference (5), and used in obtaining the data presented in this report, records the number of drops, the drop height, and the approximate drop time for the three principal axes of a container. It is impact actuated and has a range of 15 to 120 centimeters. It consists of the four-channel specialized magnetic tape recorder and six magnetolectric drop height sensors mounted so as to sense drop height components in both polarities of the three principal axes of a container. Fifteen systems have been manufactured.

The recording unit, figures 1 and 2, for the drop height recording system consists basically of a base plate upon which are mounted coaxial supply and take-up reels, the recording head, stepping motor, batteries, timer and potted electronic assemblies for controlling stepping and signal cutout. This assembly is inclosed in a protective aluminum box, figure 3. Recording is done on motionless magnetic tape with 1.6 mm stepping after each record. No sensor signal conditioning is included other than resistive attenuation and a two-second cutout after recording. The timer is an Accutron device which has a contact closure once each hour. The time pulse and sensor signals cause tape advancement by triggering the rotary stepping motor.

Inputs to the drop height recorder are generated by six drop height sensors mounted so as to monitor the shock components felt by respective faces of an instrumented package. A sensor, figure 4, consists of a bar magnet resting on a helical compression spring within an aluminum tube about which is wound a sensing coil. A magnetic shielding sleeve surrounds the aluminum tube and coil. The compression spring and bar magnet comprise a spring mass system designed to have a natural frequency of about ten Hertz. This frequency allows accurate sensing of drop heights (impact velocities) for impact deceleration pulse durations up to twenty-eight milliseconds. A voltage proportional to the drop height





Figure 1. Drop Height Recorder, Top View. Coaxial supply and take-up reels, recording head, 7.5 volt battery, terminal board, and input connector visible.

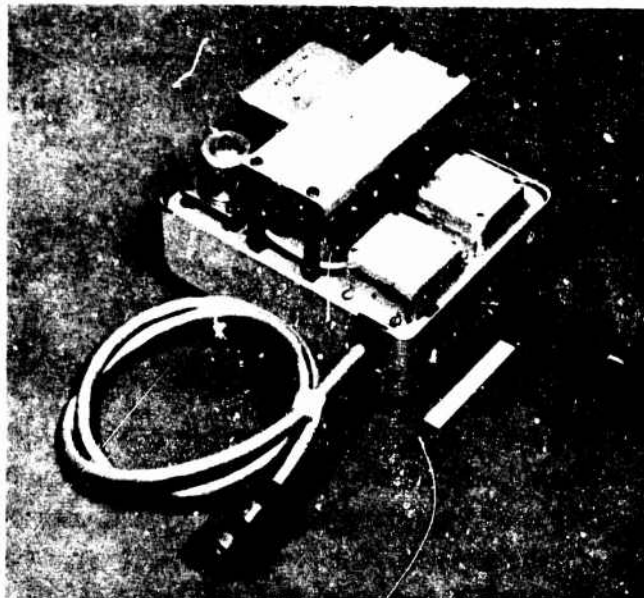


Figure 2. Drop Height Recorder, Bottom View. Potted electronic cans, 45 volt battery hold down, and rotary stepping motor visible.

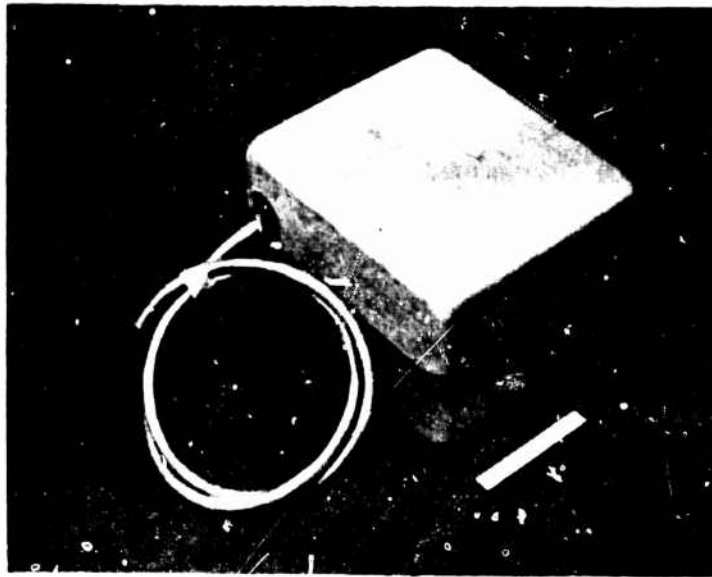


Figure 3. Protective Aluminum Cover. 18 Centimeters long by 15 centimeters wide by 12 centimeters deep.



Figure 4. Drop Height Sensor, Disassembled. Components from front to back; helical compression spring and base end cap, top end cap and bar magnet, sensing coil wound around aluminum tube, magnetic shielding sleeve. Overall assembled dimensions; 2.5 centimeters in diameter by 18 centimeters long.

component (impact velocity) in the direction of the drop height sensor's longitudinal axis is induced when the instrumented package strikes a surface with sufficient force.

The sensor outputs are magnetically stored on three tracks of 6.4 mm (1/4 inch) recording tape. The fourth track is used for time reference marks. The recorder's tape, therefore, becomes a handling history of the instrumented package for the duration of a shipment.

### III. SYSTEM PREPARATION

The drop height recording system was prepared for all data gathering shipments summarized in this report in essentially the same manner. Six unidirectional drop height transducers, two for each axis, were first securely mounted to a rigid frame approximately 41cm x 31cm x 24cm constructed of 25mm x 25mm x 3mm aluminum angles welded together. The sensor output connectors were then mated to the recorder input connector via a wiring harness similar to an umbilical cord. The recorder was then placed inside the frame as close as possible to the center of gravity and the remaining void space was filled with 32 Kg/m<sup>3</sup> polyether polyurethane cushioning material. The entire recording system was then placed in a fibreboard box which was taped shut. This then comprised an unmarked instrumented test package with a mass of approximately 11.3 kilograms and with the same dimensions as a standard number 2-1/2 - 24 can case used for subsistence items. Figure 5 shows the instrumented container being prepared for shipment.

The test package was then subjected to a series of calibration drops on a standard laboratory free fall drop test machine. The calibration series generally consisted of two or three flat drops on each of the six possible impact faces from four different drop heights between 15 and 120 centimeters. The instrumented test package was then ready for shipment. After completion of the test shipment the package was again put through a series of calibration drops. The magnetic tape was then removed from the drop height recorder and processed through a four channel tape playback unit and appropriate display device.



Figure 5. Preparation of Instrumented Container for Shipment. Visible components; polyurethane cushioning, aluminum frame, one drop height sensor, drop height recorder, and fibreboard box. Container dimensions; 41 centimeters long, by 31 wide, by 24 centimeters deep.

The calibration drops were used to derive a calibration curve for each of the six sensors. Figure 6, read left to right, is an oscilloscope trace of the single channel playback of a representative calibration series. This particular one axis (bottom/top) series consisted of a total of twenty drops executed in the following sequence; three 30 centimeter drops on first the package bottom and then the package top, followed by three 60 centimeter drops on the package bottom and then top, followed by two 90 centimeter drops on the package bottom and then top, and finally two 120 centimeter drops on the bottom and then top. Bottom drops cause a greater negative deflection of the oscilloscope trace and top drops cause a greater positive deflection. Therefore the heights of the drops in this calibration series with a bottom impact surface are indicated by the negative amplitude of the first, third, fifth, and seventh set of traces. The heights of the drops with a top impact surface are indicated by the positive amplitude of the second, fourth, sixth, and eighth set of traces. A calibration curve for both sensors in this axis can

be drawn by relating the average playback pulse amplitude for each set of drops to the known drop height.

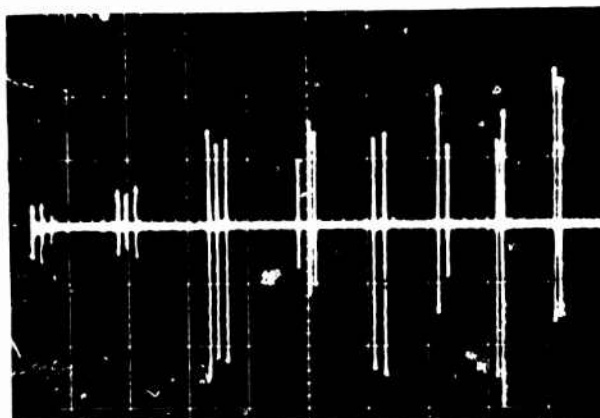


Figure 6. Representative Calibration Series, Oscilloscope Trace. Single channel playback with horizontal axis set at 0.2 seconds/division and vertical axis set at 1.0 volts/division.

The height of drops experienced during shipment can then be determined by measuring the amplitude of shipment drop pulses, Figure 7, and comparing them to the calibration curve for the corresponding sensor. Simultaneous playback pulses from all three drop height channels would indicate a corner drop, pulses from two out of three channels would indicate an edge drop, and a pulse from only one channel would indicate a flat drop.

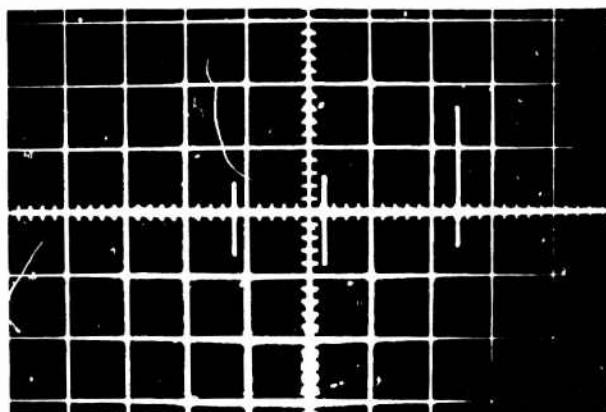


Figure 7. Representative Shipment Series, Oscilloscope Trace. Single channel playback with horizontal axis set at 0.2 seconds/division and vertical axis set at 1.0 volts/division.

#### IV. SHIPMENT

Initial field testing of the prototype drop height recording systems was accomplished by routing the instrumented test packages via truck and airplane from Natick, Massachusetts to Wright Patterson Air Force Base, Ohio and return. While at Wright Patterson Air Force Base the instrumented packages were subjected to a series of test drops from known heights using a free fall drop tester. The purpose of the initial field shipments was to test both the accuracy and reliability of the prototype recording systems under actual field conditions as well as to gather drop height data during in-transit handling operations.

After sufficient experience and confidence were gained in drop height recorder system operation, the scope of data gathering shipments was increased.

Several air mail shipments, involving transport by truck and plane, were again made to Wright Patterson Air Force Base, Ohio, approximately 1,800 kilometers round trip; as well as to the Redstone Arsenal in Huntsville, Alabama, approximately 3,200 kilometers round trip. These instrumented packages were primarily subjected to manual handling operations.

A five month data gathering shipment of four individually instrumented containers was made to Rota, Spain in support of a packaging waste reduction study, reference (6). The recorders were packaged and calibrated at Natick and air mailed to the Navy Supply Center, Charleston, South Carolina. At Charleston each instrumented package was positioned in the bottom center position of a unitized load of subsistence items and the loads were then capped and strapped. The subsistence items were then placed aboard a Navy ship, transported to Rota, Spain, offloaded, and placed in warehouse storage for twenty-eight days. After storage the subsistence items were again loaded aboard a Navy ship, returned to Charleston, South Carolina and offloaded. From there the loads were transported by truck to Williamsburg, Virginia, where they were subjected to various additional handling procedures as a test of the packaging, and then disassembled. The instrumented containers were removed and returned by air mail to Natick. Each instrumented package was subjected to fork-lift, cargo net and manual handling during the 12,000 kilometer round trip.



Several short shipments were made with the cooperation of the General Services Administration. Unmarked instrumented containers were placed in various storage locations in the Hingham, Massachusetts Supply Depot. They were then requisitioned and handled by standard warehouse procedures and delivered to Natick by commercial carrier or parcel post. The handling operations included those that occurred in the semi-automated depot as well as those during actual loading, delivery, and unloading.

Additional data gathering shipments were made with the cooperation of the United Parcel Service East New England District Office. In a representative shipment, six instrumented packages were picked up in Natick; routed through the Worcester, Massachusetts Hub; processed and sorted; trucked to the Portland, Maine Hub; sorted; trucked to Lewiston, Maine; returned to the Portland, Maine Hub; sorted; returned to the Worcester, Massachusetts Hub; sorted; and then routed through the entire circuit for a second time before being returned to Natick. Sorting operations were accomplished automatically by conveyor systems and loading/unloading operations were accomplished manually.

It must be remembered, however, that the drop height recording system was designed with a minimum activation threshold of 15 centimeters to make it insensitive to small repetitious shocks which may occur while actually being transported. Therefore, the particular mode of transportation selected and the total distance travelled were not as important in these studies as the number and type of handling and sorting operations experienced during an entire shipment. With this in mind, the majority of strictly data gathering shipments were made between points in New England, because this facilitated keeping an accurate log of the locations, type, and number of handling operations involved and permitted the accumulation of more drop height data per unit of shipping time.

## V. RESULTS

### A. Operational Problems

Initial field tests of the drop height recording systems resulted in a high failure rate of the prototype recorders caused by the normal shock and vibration levels associated with transportation. These operational failures disclosed several recorder problem areas which had not been detected during laboratory evaluation tests. The failures were classified into two groups; design deficiency failures and reliability failures.

The design deficiency failures resulted from inherent errors in the basic design and were evidenced by such symptoms as signal saturation, channel crosstalk, random spikes, inadequate cushioning, inadequate transducer impact strength and frame ringing. These failures were corrected as they occurred and the recorder system design was modified accordingly to prevent recurrence.

The reliability failures were primarily caused by pinched leads, broken printed circuits, cold solder joints, and component movement. These failures necessitated a complete review of the recording system with the prime purpose of improving the system reliability against the transportation shock and vibration environment through the application of state-of-the-art design and assembly approaches. This review was accomplished by the US Army Electronics Command located at Fort Monmouth, New Jersey. It resulted in a more rugged recorder design with improved cushioning, connectors, tiedowns, wiring routing, and mounting of transducers, batteries, and components. All previously manufactured recorders were modified in accordance with the improved design.

#### **B. System Accuracy**

In addition to the operational problems stated, the problem of system accuracy had to be confronted. The average percent error of the complete recorder/playback system during static tests, (recorder not subjected to impact), had been measured in the laboratory to be in the range of  $\pm 10\%$  for a pulse input accuracy of  $\pm 2\%$ . This error was primarily caused by normal variations in tape magnetization due to non-uniformity of particle density, irregular dispersion of particles, or irregular particle size in the tape emulsion as well as to tape tracking errors and tape to tape head distance fluctuations.

The average percent error of the recorder/playback system during dynamic test, (recorder subjected to impacts), under laboratory conditions had been measured to be in the range of  $\pm 3\%$  to  $\pm 18\%$  as the impact shock level to the recorder increased from 20 g's to 300 g's. This additional inaccuracy resulted from possible movement of the magnetic tape across the record head at impact and the addition of the drop height sensor, with a stated accuracy of  $\pm 10\%$ , to the system.

The average percent error of the recorder/playback system test drops conducted during the Wright Patterson Air Force Base field shipments was measured in the range of  $\pm 10\%$

to  $\pm 25\%$  of the actual drop height value with average error increasing with drop height and becoming most significant above one metre. This increase in error was caused by differences in impact surfaces and an approximate  $15^\circ$  threshold insensitivity of the drop height sensor to edge and corner drops. That is, for edge or corner impacts, the secondary sensor which is mounted perpendicular to the primary drop height sensor must be inclined at least  $15^\circ$  to the horizontal before it will sense the impact.

Careful analysis of playback data from actual shipments could decrease the system error. All instrumented packages were subjected to a calibration drop series immediately prior to and immediately following shipment. If the two calibration curves resulting from these two drop tests did not match, then the actual field drop data from that particular shipment was suspect and consequently was not added to the total of all shipments. Only one instance of calibration shift was recorded during the field tests.

If the oscillograph playback trace for a particular in-transit drop exhibited possible evidence that the magnetic tape had moved, due to the severity or orientation of impact while a recording was in process, then that piece of datum was listed as a drop of undetermined magnitude. This condition occurred occasionally and generally indicated that the magnetic tape on the recording unit was in a state of excessive tension caused by a malfunction in the recorder indexing system.

### C. Recorded Data

The following data is summarized from all the individual drop height recorder field tests conducted to date. A total of 312 individual drops exceeding 15 centimeters were recorded during the total of 1,500 days and 80,000 kilometers of instrumented shipment through various transportation systems. The instrumented packages had a mass of 11.3 kilograms and length, width, and depth respectively of 41cm x 31cm x 24cm.

Figure 8 is a histogram in five centimeter increments of the recorded drop height distribution. During shipment the packages experienced a large number of small drops and relatively few higher drops. The median drop height was 25 centimeters. The average drop height was 35 centimeters.

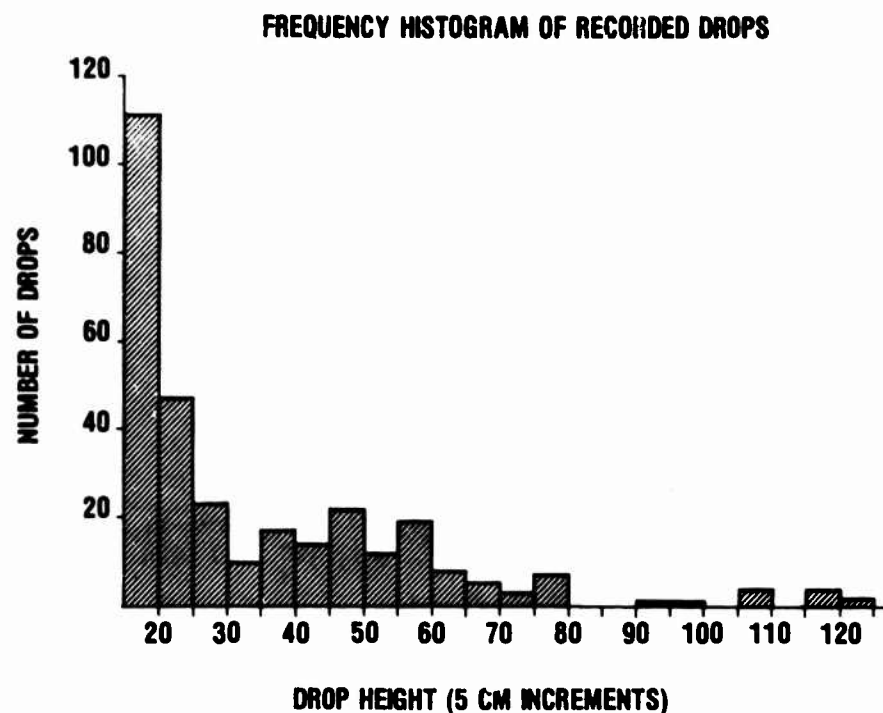


Figure 8. Frequency Histogram of Recorded Drops. Distribution of 312 recorded drops in 5 centimeter increments. System activation threshold prohibits recording drops of less than 15 centimeters.

Figure 9 is a graphical presentation of the same data normalized to one hundred percent. Ninety percent of the recorded drops were below 64 centimeters.

A statistical analysis of the data utilizing the Bernoulli Method, with no assumption as to the drop height distribution function, indicates that at the ninety-five percent confidence level, ninety percent of the expected drop heights would be below 70 centimeters. Figure 10 presents the results of the analysis at the ninety-five percent confidence level for a range of probabilities.

Ninety-six, three, and one percent of the recorded drops were classified as flat, edge, and corner drops respectively. A preponderance of the flat drop impact shocks, seventy percent, were experienced by the bottom impact surface of the container. Eighty, twelve, and eight percent of the flat drops were experienced by the top/bottom, front/back, and side/side surface combinations of the container respectively.

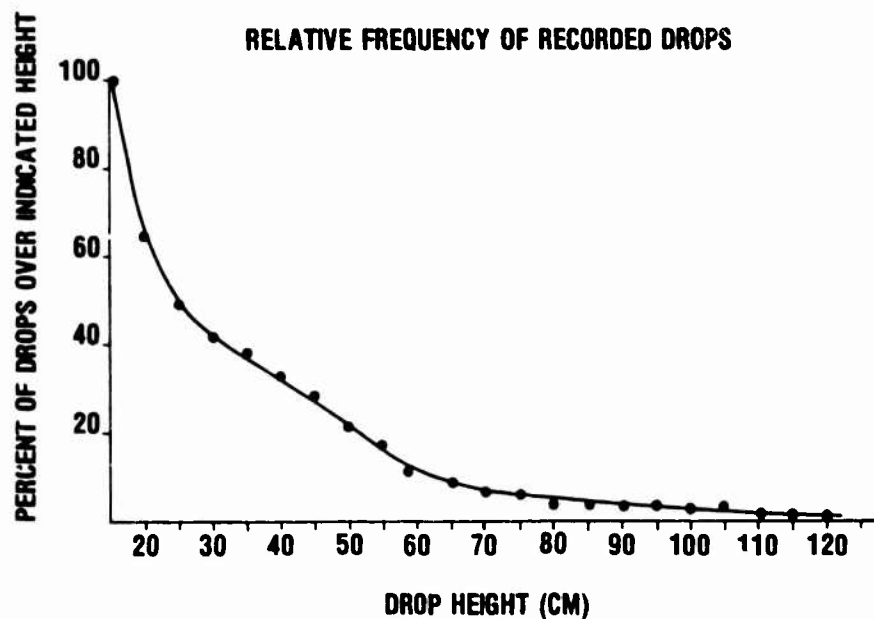


Figure 9. Relative Frequency of Recorded Drops. Distribution of 312 recorded drops normalized to one hundred percent. System activation threshold prohibits recording drops of less than 15 centimeters.

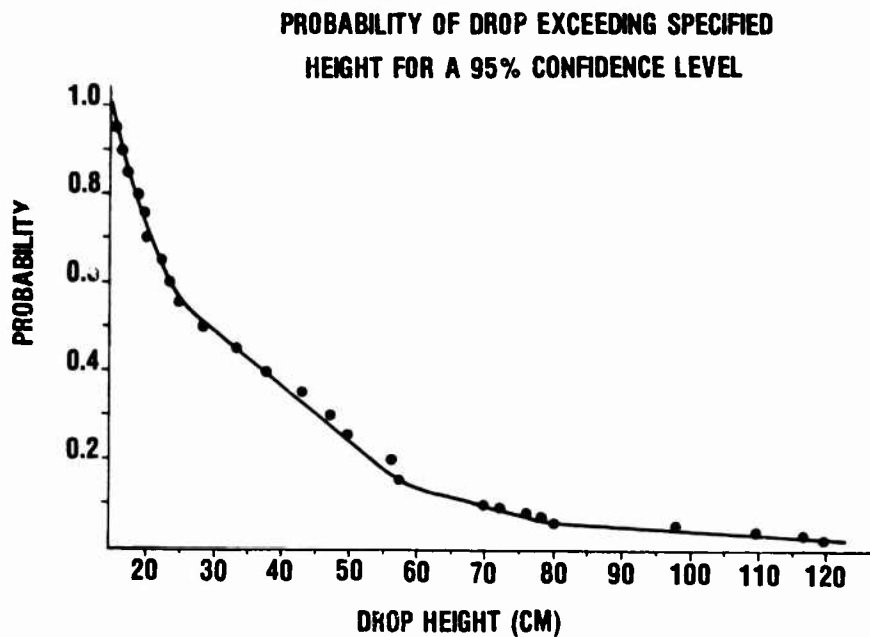


Figure 10. Drop Height Probability Distribution. Probability of observed shock exceeding a given height, at the ninety-five percent confidence level.

It is interesting to note that the average drop height for the limited number of edge and corner impacts recorded was 64 centimeters as compared to 34 centimeters for strictly flat impacts only. Normal placement of a container would result in an approximate flat drop, whereas an unintentional drop would most likely result in an edge or corner impact. This may indicate that unintentional drops are approximately twice as severe as normal handling.

It was not an intent of this study to compare the various transportation systems utilized, and a rigorous comparison was not made because some systems were used much less extensively than others. However, during analysis of the data, no trend was noted of one transportation system handling a package more carefully than another.

## VI. CONCLUDING REMARKS

Classification of the actual shock environment of the package during shipment is a difficult task because of the many handling and logistic variables involved, the complexities and cost of the instrumentation required for a specific limited application, and the shipping and instrumentation time required to collect sufficient data. The studies summarized in this report were a step in an orderly program of instrumentation development, test, and use, directed towards providing a statistical representation of the actual transportation environment.

Several trends were apparent for the container size and mass instrumented:

- a. The packages experienced a large number of small drops and relatively few higher drops.
- b. The median drop height was 25 centimeters.
- c. The average drop height was 35 centimeters.
- d. Ninety percent of the drops were below 64 centimeters.



- e. Statistically, at the ninety-five percent confidence level, ninety percent of the expected drop heights would be below 70 centimeters.
- f. The bottom surface of the container received the majority, seventy percent, of the impact shocks.
- g. Collectively; eighty percent, twelve percent, and eight percent of the flat drops were experienced by the top/bottom, front/back, and side/side surface combinations of the container, respectively.
- h. Edge and corner drops occurred from greater average drop heights than flat drops.

## VII. FUTURE EFFORT

Future studies with the drop height recording system will consider the effects of package size, weight, and marking as well as transportation system used on the frequency and intensity of package drop height.

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